CORE
Metadata, citation and similar papers at core.ac.uk
Provided by Elsevier - Publisher Connector

Available online at www.sciencedirect.com
SciVerse ScienceDirect
Physics Procedia 41 (2013) 31 – 37
Physics Procedia

Lasers in Manufacturing Conference 2013

Electrochemistry corrosion properties of pulsed laser welding Hastelloy C-276

G. Ma[a]*, F. Niu[a], D. Wu[a], Y. Qu[b]

[a]*Key Laboratory for Precision and Non-traditional Machining Technology of Ministry of Education, Dalian University of Technology, Dalian, Liaoning Province, 116024, PR of China*
[b]*Dalian University of Technology, Dalian, Liaoning Province, 116024, PR of China*

Abstract

Based on the welding quality requirement of Hastelloy C276 in the extreme environment, the electrochemistry corrosion property of laser welding Hastelloy C276 was evaluated in the neutral, acid and alkaline solutions, and the corroded surface was observed by the co-focal laser scanning microscope to confirm the corrosion mechanism. The results indicated, the corrosion trend of the weld was weaker than that of base metal in the neutral and acid solutions, but in the alkaline solutions, the corrosion trend of the base metal was weaker. However, the corrosion rate of the weld was much slower than that of base metal in all solutions. At the point of corrosion mechanism, in the acid and alkaline solutions, the base metal and weld showed the uniform corrosion. However, in the neutral solution, the selective corrosion and intergranular corrosion occurred in the base metal and the weld, respectively.

© 2013 The Authors. Published by Elsevier B.V. Open access under CC BY-NC-ND license.
Selection and/or peer-review under responsibility of the German Scientific Laser Society (WLT e.V.)

Keywords: Pulsed Laser Welding; Hastelloy C276; Electrochemistry Corrosion

1. Introduction

Hastelloy C-276 (a nickel-molybdenum-chromium alloy) with the excellent corrosion-resistant property is extensively applied in the extreme environment such as hot contaminated media, chlorine, formic and acetic acids, acetic anhydride, and seawater and brine solutions [1]. So, aiming at the special working environment,

* Corresponding author. Tel.: +86-411-84707625; fax: +86-411-84707625.
E-mail address: gyma@mail.dlut.edu.cn.

1875-3892 © 2013 The Authors. Published by Elsevier B.V. Open access under CC BY-NC-ND license.
Selection and/or peer-review under responsibility of the German Scientific Laser Society (WLT e.V.)
doi:10.1016/j.phpro.2013.03.048

it is important to improve the welding method to ensure the service life of C-276 welding structure. So far the argon arc welding has been widely adopted to join the sheet of C-276 in the huge structure [2-4]. Besides the traditional arc welding, the high energy beam welding was also a welding method to join Hastelloy C-276 [5-7]. However, in the extreme environmental industry, the thin Hastelloy C-276 has been applied in the manufacture of pipe and large container. So, the corrosion resistant property of welding structure is an important performance for evaluating the feasibility of welding method.

Although it was proved that the pulsed laser welding could decrease the trend of brittle phase formation to be beneficial to holding the corrosion-resistant property of Hastelloy C-276, the corrosion-resistant property of weld in different solutions was not investigated. In the present work, by the electrochemistry corrosion test in three solutions (NaCl, HCl and NaOH), the corrosion-resistant property of Hastelloy C-276 pulsed laser weld was estimated, and then the microstructure characteristic of corroded surface analyzed by the co-focal laser scanning microscope.

2. Experiment

In the experiment, the 0.5 mm thickness Hastelloy C-276 was employed. The pulsed 1064 nm Nd:YAG laser was used to join the Hastelloy C-276 with the pure Ar as the gas-shielding, and the image of set-up was shown in Fig.1. According to the previous investigation, the well smooth weld with free defect could be obtained under the 1.5 J, 6 ms, 30 Hz, 100 mm/min and -1 mm defocus condition (the weld cross section was shown in Fig.2). In the Fig.2, it was found, the thickness of the weld was the same as that of the base metal, and there was no any visible heated affected zone. Hence, in the corrosion test, welding samples were prepared according to the welding parameters mentioned above.

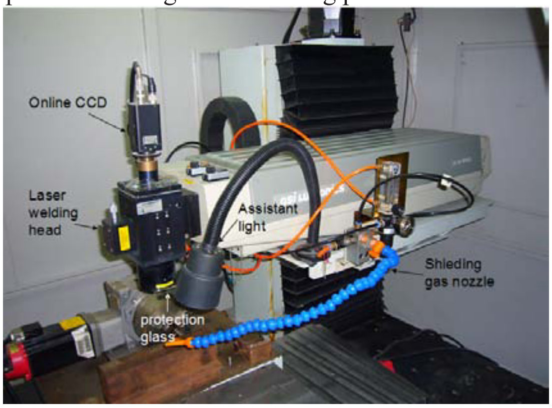

Fig.1. Image of set-up

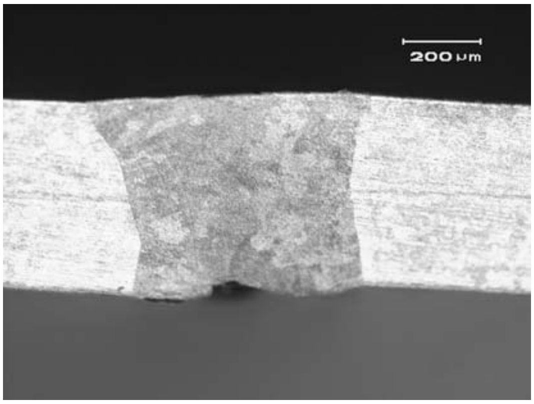

Fig.2. Weld cross-section
(Welding parameters: 1.5 J, 6 ms, 30 Hz, 100 mm/min and -1 mm defocus)

The welding samples, which were used in the electrochemistry corrosion test, were cut along the weld longitudinal direction at the mid of weld. Then the cut samples and base metal were ground by the 600#, 800# and 1200# SiC abrasive paper sequently and in turn polished by the 2.5 μm emery paste. Before the corrosion test, the samples were insulated by the insulating gel except the would-corroded area.

The electrochemistry corrosion test was carried on PARSTAT 2273 Advanced Electrochemical System with a standard three-electrode platform, and the Fig.3 showed the schematic of Electrochemical System. The weld or base metal was taken as a working electrode, the saturated calomel as a reference electrode and the platinum plate as a counter electrode. The corrosive solutions were 3 g NaCl+100 ml H_2O, 3 g NaCl+5 ml HCl +100 ml H_2O, 3 g NaOH+3 g NaCl +100 ml H_2O, respectively. The scanning rate was 5 mV/s. After the corrosion test, the corroded surface was observed by Olympus LEXT CLS4000 co-focal laser scanning microscope (CLSM).

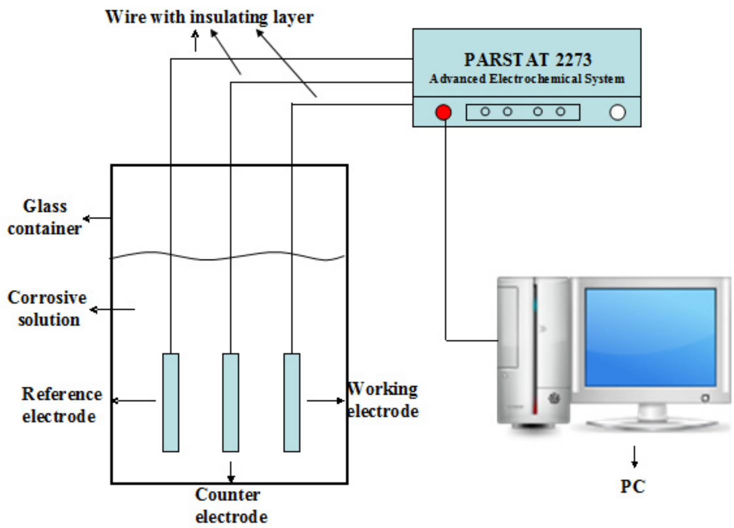

Fig.3. Schematic of Electrochemical System

3. Results and Discussion

3.1. Electrochemistry corrosion characteristic in the acid solution

Fig. 4 showed the polarization curves of weld and base metal in 3 g NaCl+5 ml HCl+100 ml H_2O solution (acid solution). It was seen, the corrosion potential (E_{corr}) of weld was nearly the same as that of the base metal, but the corrosion current (i_{corr}) of weld was nearly one six-hundredth of that of base metal. Meanwhile, in the both polarization curves, there were three potential sections, including less than 0 V, 0 to 1.0 V and more than 1.0 V.

In the section of less than 0 V, the E_{corr} and i_{corr} were obtained by the Tafel extrapolation. In the base metal, the E_{corr} and i_{corr} were -249.406 mV and 8.019×10^{-7} A/cm^2, respectively. In the weld, the E_{corr} and i_{corr} were -230.694 mV and 1.417×10^{-9} A/cm^2, respectively. From the standpoint of thermodynamics which is decided by the E_{corr}, the corrosion trend of weld was the same as that of base metal, however from the standpoint of kinetics which is decided by the i_{corr}, the corrosion rate of weld was much less than that of base metal. In the section of 0 to 1.0 V, the obvious passivation was found in the base metal, but in the weld, this phenomenon was not presented. This indicated, the passive film could be formed on the base metal, but in the weld, there was no passivated period. This may be due to the element micro segregation in the weld. In the sections of more than 1.0 V, the curve of weld showed the same trend as that of base metal. According to the results above, it was concluded that, in the acid solution, the corrosion resistance in the weld joined by the pulsed laser welding was superior to that in the base metal.

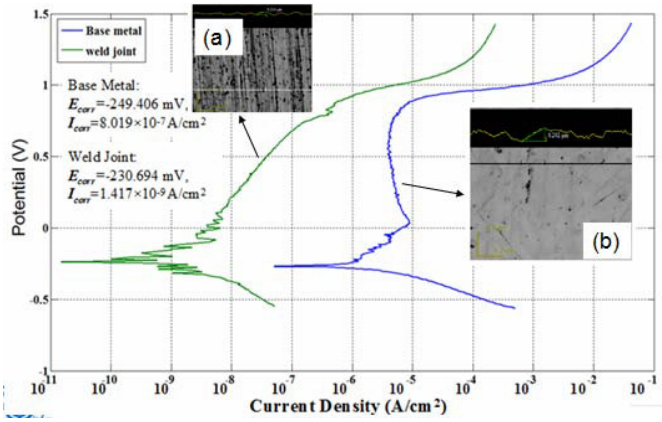

Fig.4. Polarization curves of weld and base metal in 3 g NaCl+5 ml HCl+100 ml H_2O solution

Although the corrosion trend and rate were obtained by the polarization curves, the corrosion mechanism, which was the valuable evaluation to the corrosion action, was not clear. For confirming the corrosion mechanism, the corroded surface was observed by CLSM. The morphology of corroded surface in the base metal and weld was shown in embedded (a) and (b) of Fig.4. It was found, in the base metal, the corrosion morphology presented the nearly uniform corroded surface, and the difference of roughness was just less than 0.3 μm. Considering the element nearly-uniform distribution in the base metal, it indicated the corrosion mechanism of base metal in the acid solution was the uniform corrosion. In the weld, the same corroded surface was also observed, and the difference of surface was also less than 0.3 μm. This indicated that in the weld, the uniform corrosion was the primary corrosion mechanism, which had no concern with the element segregation. The results above indicated, the base metal and weld both showed the uniform corrosion mechanism. Hence, it was concluded the corrosion essence in the acid solution was not obviously impacted by the pulsed laser welding.

3.2. Electrochemistry corrosion characteristic in the alkaline solution

Fig. 5 showed the polarization curves of weld and base metal in 3 g NaOH+ 3 g NaCl+100 ml H_2O solution (alkaline solution). It was seen, the E_{corr} of weld was much lower than that of the base metal, but the i_{corr} of weld was nearly one fiftieths of that of base metal. Also, in the both polarization curves, there were two potential sections, including less than 0 V and more than 0 V.

In the section of less than 0 V, the E_{corr} and i_{corr} were obtained. In the base metal, the E_{corr} and i_{corr} were -239.706 mV and 1.078×10^{-5} A/cm^2, respectively. In the weld, the E_{corr} and i_{corr} were -414.499 mV and 2.412×10^{-7} A/cm^2, respectively. The results indicated, the corrosion trend of weld was stronger than that of base metal, however the corrosion rate of weld was much less than that of base metal. In the section of more than 0 V, the curve of weld showed the same trend as that of base metal, and there was no passive period regardless of in the base metal or weld. According to the analysis above, it was concluded that, in the alkaline solution, the weld was easier to beginning corrosion than the base metal. But, after corrosion initiation, the corrosion resistance of weld was superior to that of the base metal.

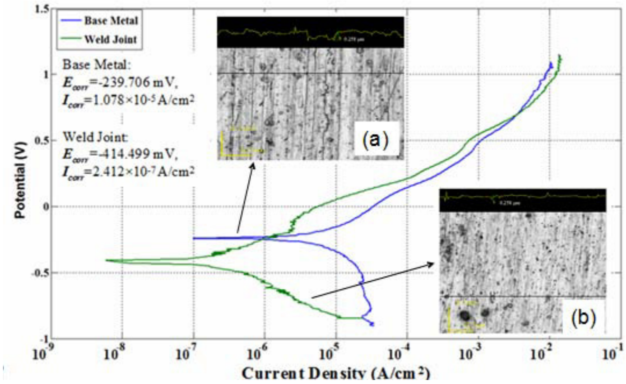

Fig.5. Polarization curves of weld and base metal in 3 g NaCl+3 g NaOH+100 ml H_2O solution

By observation to the corroded surface, it was found that the corroded surfaces in the base metal and weld both presented the uniform corrosion characteristic, and the difference of roughness was less than 0.3 µm (shown in embedded (a) and (b) of Fig.5). This indicated that, regardless of in the weld or base metal, the corrosion mechanism in the alkaline solution was nothing to do with the element distribution, and the corrosion essence in the alkaline solution was also not obviously impacted by the pulsed laser welding.

3.3. Electrochemistry corrosion characteristic in the neutral solution

Fig. 6 showed the polarization curves of weld and base metal in 3 g NaCl+100 ml H_2O solution (neutral solution). It was seen, the E_{corr} of weld was nearly the same as that of the base metal, but the i_{corr} of weld was the half of that of base metal. Meanwhile, in the both polarization curves, there were four potential sections. They were the sections of less than -0.2 V, -0.2 to 0 V, 0 to 1 V and more than 1 V, respectively.

In the section of less than -0.2 V, the E_{corr} and i_{corr} were obtained by the Tafel extrapolation. In the base metal, the E_{corr} and i_{corr} were -273.355 mV and 1.222×10^{-8} A/cm^2, respectively. In the weld, the E_{corr} and i_{corr} were -253.118 mV and 5.818×10^{-9} A/cm^2, respectively. So, the corrosion trend of weld was the same as that of base metal, however the corrosion rate of weld was the half of that of base metal. In the section of -0.2 to 0 V, the obvious passive transition was found in the base metal, but in the weld, this transition was not presented. It was considered that the phenomenon of unobvious passive transition in the weld may be due to the element micro segregation. In the sections of 0 to 1 V and more than 1 V, the curve of weld showed the same trend as that of base metal, and it indicated the corrosion process in the weld was nearly same as that in the base metal. According to the analysis above, it was concluded that, in the neutral solution, the corrosion resistance in the weld joined by the pulsed laser welding was a little superior to that in the base metal.

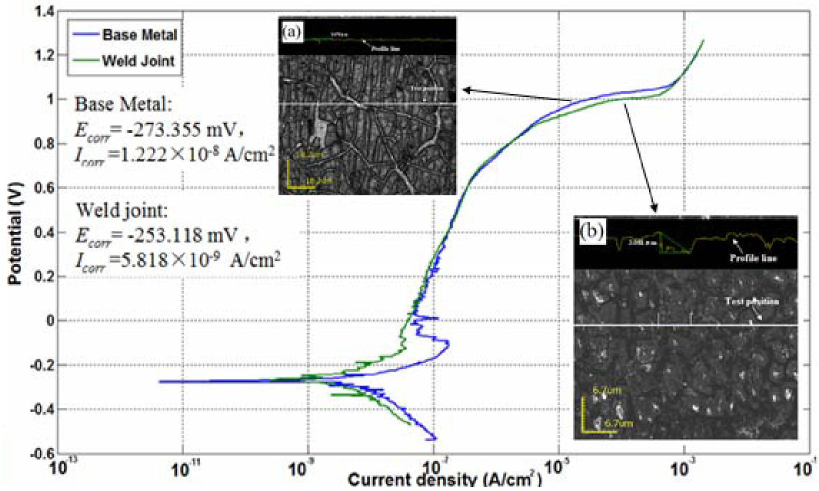

Fig.6. Polarization curves of weld and base metal in 3 g NaCl+100 ml H_2O solution

After the electrochemical corrosion, the corroded surface was also observed by CLSM. The morphology of corroded surface in the base metal and weld was shown in embedded (a) and (b) of Fig.6. It was found, the corrosion morphology in the base metal presented the obvious selective corrosion, but the corroded boundary and body did not present the obvious corrosion difference with just less than 1 μm (the profile line was shown at the top of Fig.6 embedded (a)). Considering the element nearly-uniform distribution in the base metal, it indicated that this selective corrosion had concern with the slight difference of element distribution. In the weld, the intergranular corrosion, which had concern with the element micro segregation, was observed, and the difference of roughness reached 3μm (the profile line was shown in the Fig.6 embedded (b)). The results indicated, the base metal showed the selective corrosion mechanism, but the difference between the boundary and body was much little. In contrast, in the weld, the intergranular corrosion was the primary corrosion mechanism. Hence, it was concluded that the corrosion essence in the neutral solution was not obviously impacted by the pulsed laser welding.

4. Conclusion

This investigation was focused on the electrochemistry corrosion properties of Hastelloy C-276 weld in the pulsed laser welding. Electrochemistry corrosion characteristics were evaluated in the neutral, acid and alkaline solutions. The conclusions are summarized below.

(1) In the acid solution, the corrosion resistance in the weld joined by the pulsed laser welding was superior to that in the base metal. The base metal and weld both showed the uniform corrosion mechanism, and the corrosion essence in the acid solution was not obviously impacted by the pulsed laser welding.

(2) In the alkaline solution, the weld was easier to beginning corrosion than the base metal. But, after corrosion initiation, the corrosion resistance of weld was superior to that of the base metal. The base metal and the weld both presented the uniform corrosion. Also, the corrosion essence in the alkaline solution was not obviously impacted by the pulsed laser welding.

(3) In the neutral solution, the corrosion resistance in the weld joined by the pulsed laser welding was a little superior to that in the base metal. The base metal showed the selective corrosion mechanism. In the weld, the intergranular corrosion was the primary corrosion mechanism. The difference of corrosion mechanism had concern with the element distribution.

Acknowledgements

This research was supported by the National Key Basic Research Program of MOST of P.R. China (Grant No. 2009CB724307) and the National Natural Science Foundation of China (Grant No. 51175061).

References

[1] HASTELLOY C-276 ALLOY, HAYNES International, H-2002D; 3

[2] M.J. Cieslak, G. A. Knorovsky, T.J. Headley, et al. The Use of New PHACOMP in Understanding the solidification microstructure of Nickel base alloy weld metal. *Metallurgical and Materials Transactions A* 1986; **17A**; 2107-16

[3] M.J. Cieslak, T.J. Headley, A. D. Romig, Jr. The Welding Metallurgy of HASTELLOY Alloys C-4, C-22, and C-276. *Metallurgical and Materials Transactions A* 1986; **17A**; 2035-47

[4] J.S. Ogborn, D.L. Olson, M.J. Cieslak. Influence of solidification on the microstructural evolution of nickel base weld metal. *Materials Science and Engineering A* 1995; **203**; 134-9

[5] M. Ahmad, J.I. Akhter, M. Akhtar, et al. Microstructure and hardness studies of the electron beam welded zone of Hastelloy C276. *Journal of Alloys and Compounds* 2005; **390**; 88-93

[6] D.J. Wu, G.Y. Ma, Y.Q. Guo, D.M. Guo. Study of weld morphology on thin Hastelloy C-276 sheet of pulsed laser welding. *Physics Procedia* 2010; **5;** 99-105

[7] G.Y. Ma, D.J. Wu, Z.H.Wang, Y.Q. Guo, D.M. Guo. Weld Joint Forming of Thin Hastelloy C-276 Sheet of Pulsed Laser Welding. *Chinese journal of lasers* 2011; **38**; 0603014